March 8, 1949. E. G. BAILEY ET AL Re. 23,087

CONTROL SYSTEM

Original Filed Oct. 18, 1943 5 Sheets-Sheet 1

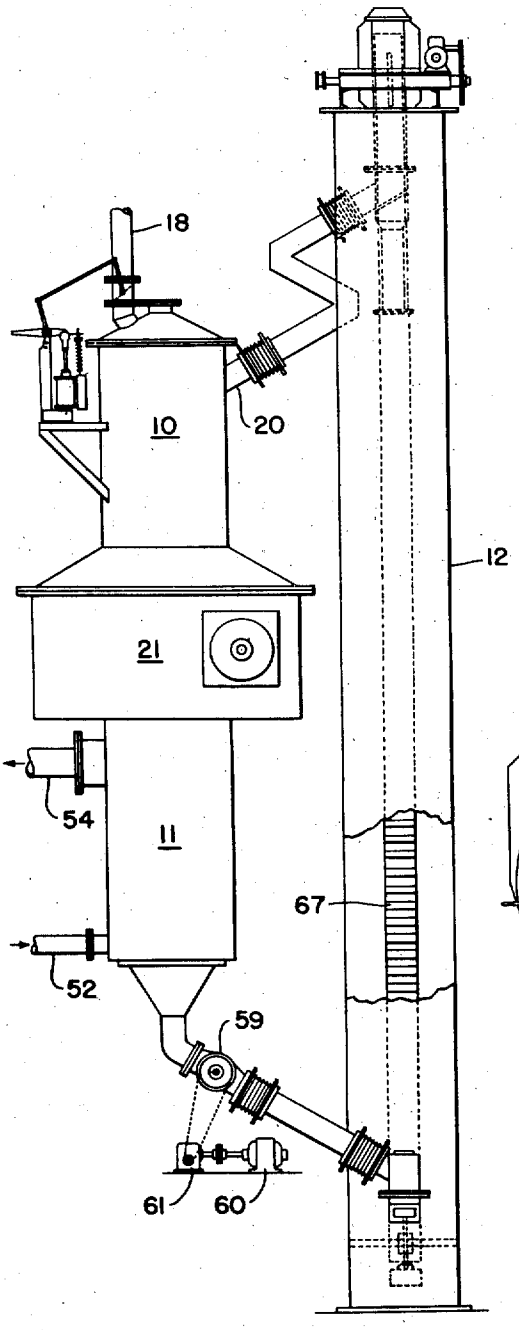


FIG. 1

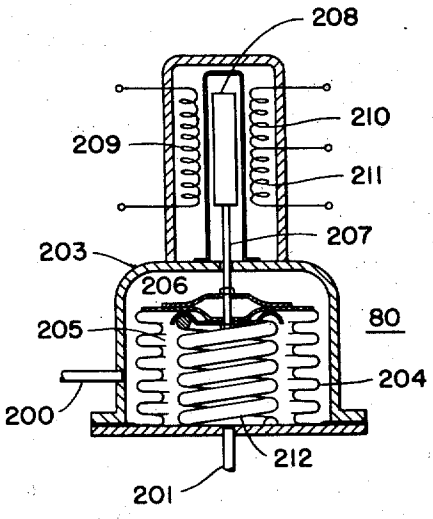


FIG. 7

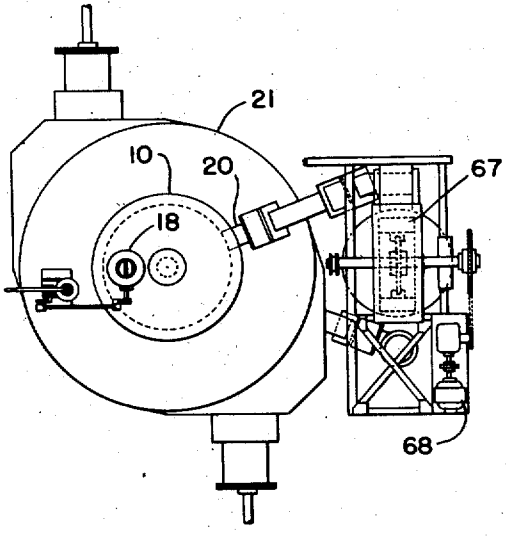


FIG. 2

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CONTROL SYSTEM

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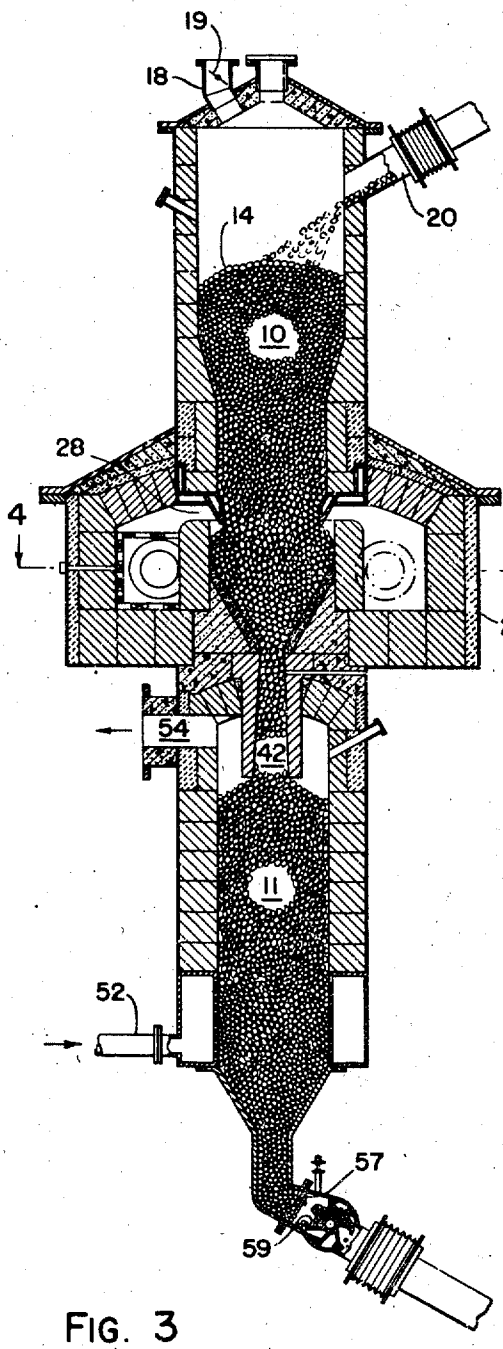


FIG. 3

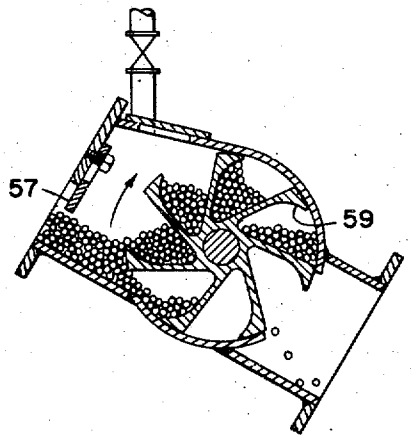


FIG. 5

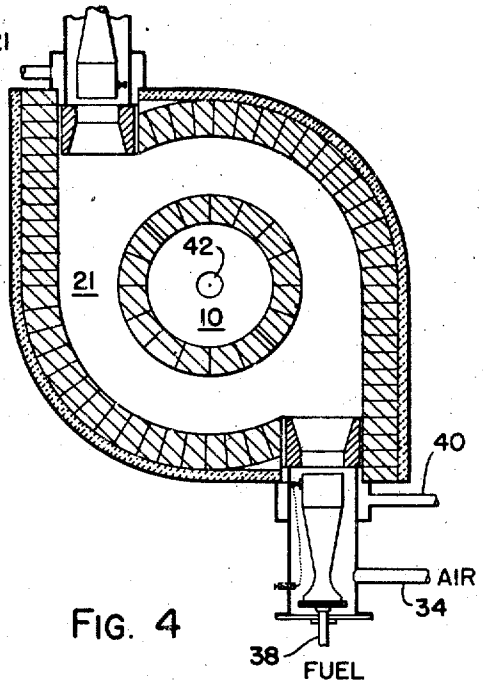


FIG. 4

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CONTROL SYSTEM

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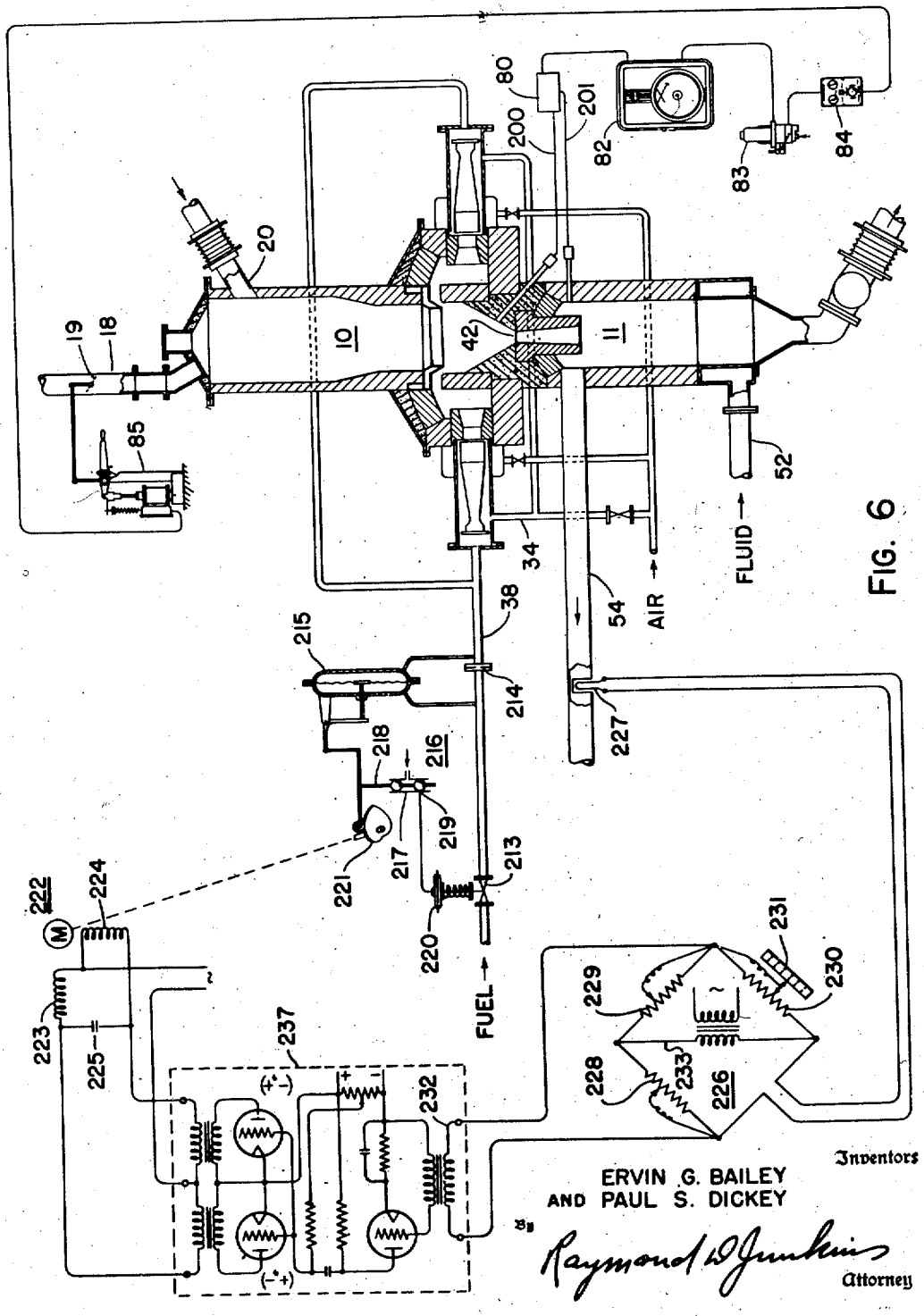


FIG. 6

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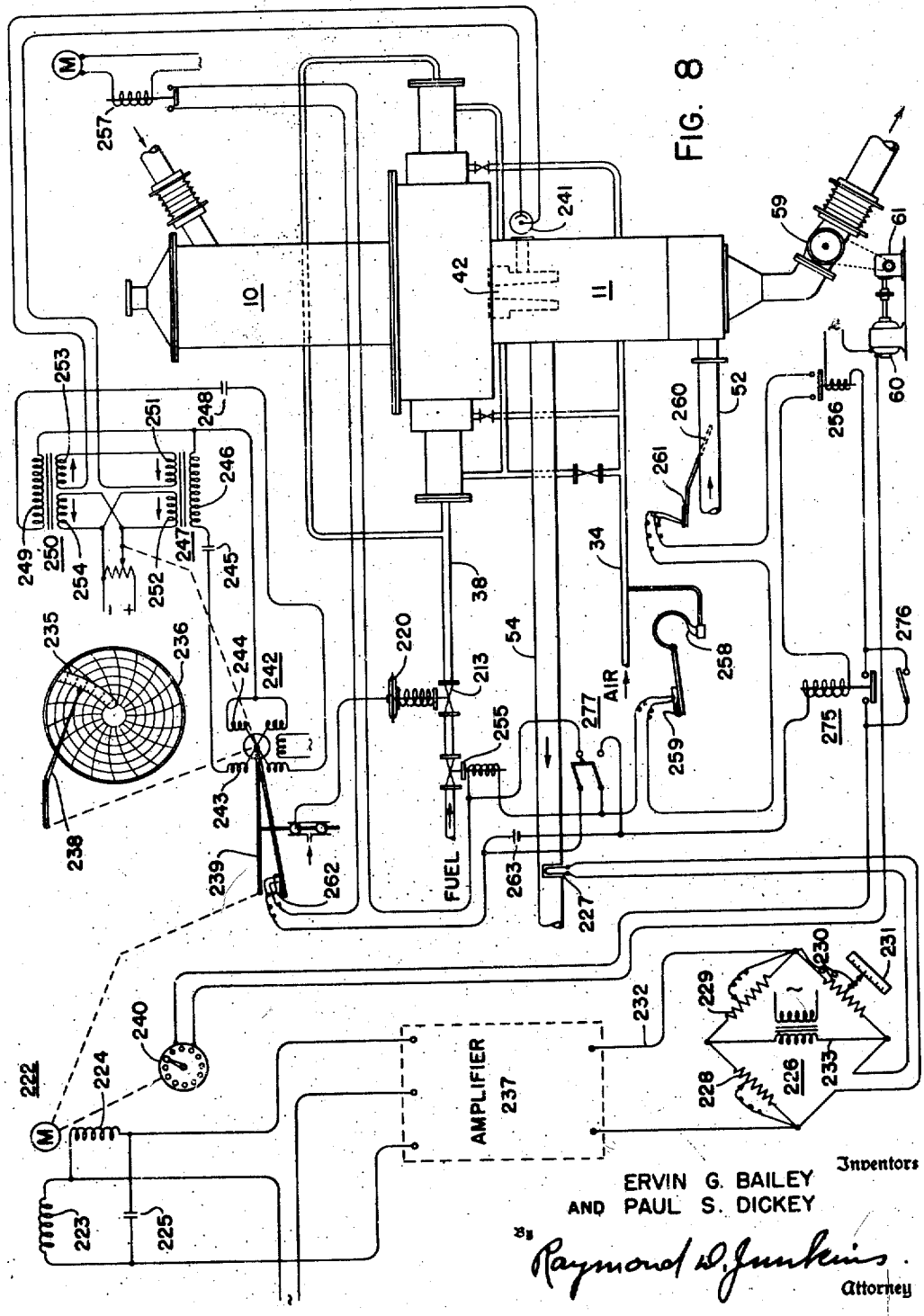
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FIG. 8



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CONTROL SYSTEM

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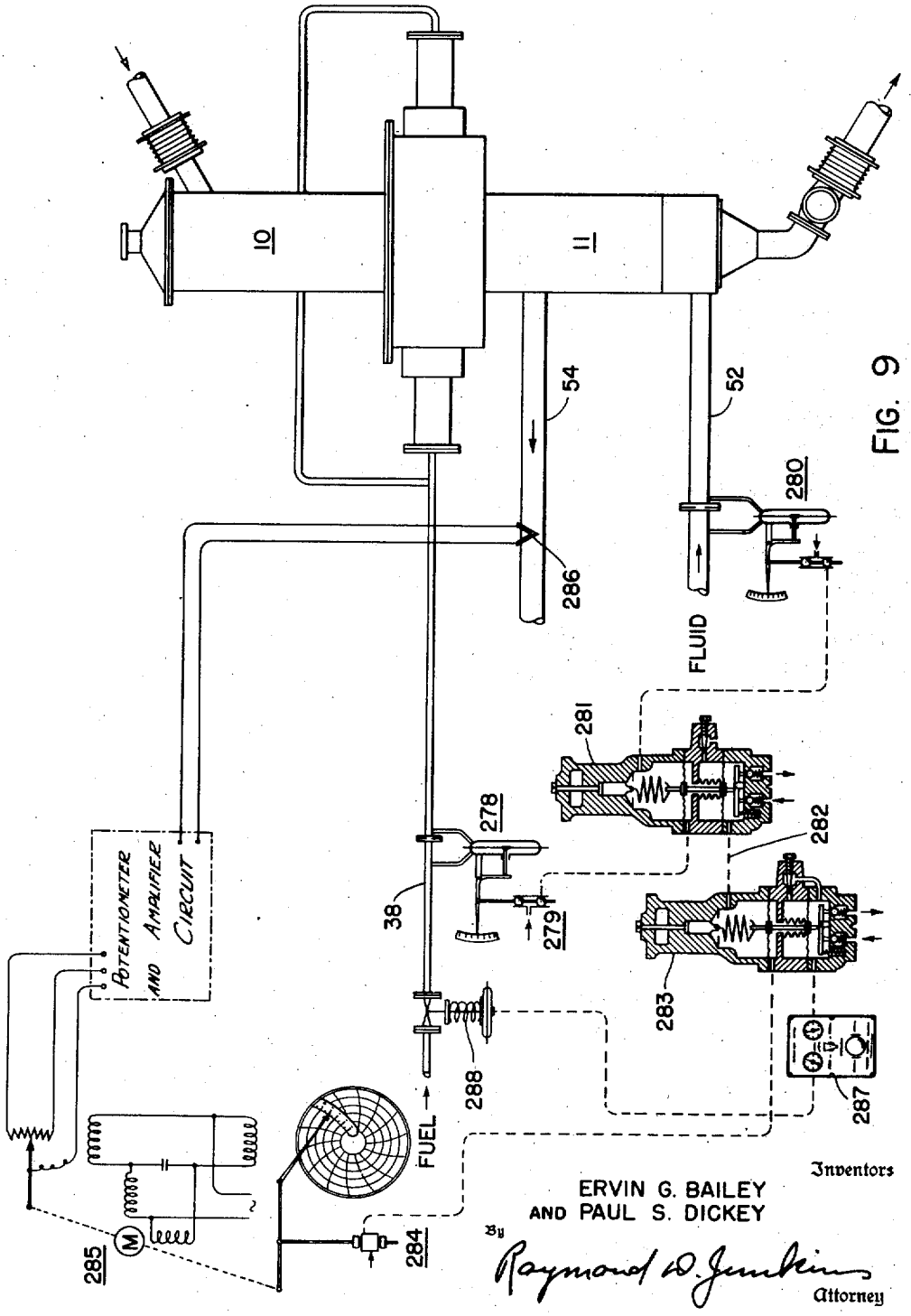


FIG. 9

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Reissued Mar. 8, 1949 Re. 23,087

UNITED STATES PATENT OFFICE

23,087

CONTROL SYSTEM

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Original No. 2,417,049, dated March 11, 1947, Serial No. 506,630, October 18, 1943. Application for reissue February 12, 1948, Serial No. 7,924

35 Claims. (Cl. 263—19)

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The present invention relates in general to the operation and control of fluid heaters of the type in which the heat transfer medium consists of a fluent gas-pervious mass of refractory material which is first heated by the passage of a heating fluid in heat transfer relation therewith and then cooled by contact with a second fluid to be heated; and more particularly to fluid heaters of the character illustrated and described in which the fluent mass of heat transfer material moves downwardly through superposed heating and cooling chambers connected by a neck or throat of reduced flow area.

The general object of our invention is the provision of a method of an apparatus for operating and controlling fluid heating apparatus of the character disclosed for continuously heating the fluid under pressure at high capacities to a uniform final temperature in a range whose upper temperature limit is dependent only upon the physical properties, such as the fusing temperature, of the refractory materials employed, with little or no contamination of the fluid being heated by the heating fluid employed and vice versa, without subjecting any included metallic parts to unsafe operating temperatures or requiring special corrosion and heat resistant alloys for metal operating temperatures above 900° F., and with a relatively high overall thermal efficiency.

A further object is the provision of a method and apparatus for automatically controlling the operation of such a fluid heater to provide continuous uniform leaving temperature of the heated material under continuous or varying rates of operation as may be desired.

Another object of our invention is the provision of method and apparatus for safely operating such a fluid heater at different rates of operation. Such a system includes protective and interlock apparatus sensitive to emergency or adverse conditions, for protecting not only the heater but to insure against producing a heated fluid of a temperature dangerously above or below the optimum value.

The construction and arrangement of the fluid heater here under consideration, as well as its general mode of operation, is disclosed in the copending application of Ervin G. Bailey and Ralph M. Hardgrove, Serial No. 502,580, now Patent No. 2,447,306, to which reference may be had for a fuller explanation of those features of construction and operation which are not a part of the present invention.

Our present invention particularly encompasses

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certain preferred methods of an apparatus for controlling the operation of such a fluid heater as is described in said copending application of Bailey and Hardgrove. The features of novelty which characterize our present invention are pointed out with particularity in the claims annexed to and forming a part of this specification. For a better understanding of the invention, its operating advantages and specific objects attained by its use, reference should be had to the accompanying drawings and descriptive matter in which we have illustrated and described preferred embodiments of our invention.

In the drawings:

Fig. 1 is an elevation, partly in section, of a pilot plant unit constructed in accordance with the invention of Bailey and Hardgrove, the structural supports being omitted for purposes of clarity.

Fig. 2 is a plan view of the apparatus shown in Fig. 1.

Fig. 3 is an enlarged sectional elevation of a portion of the apparatus shown in Fig. 1.

Fig. 4 is a horizontal section taken on the line 4—4 of Fig. 3.

Fig. 5 is an enlarged view of part of the apparatus shown in Fig. 3.

Fig. 6 diagrammatically illustrates one control system embodiment of our invention.

Fig. 7 is a sectional elevation, partially diagrammatic, of a pressure differential responsive device.

Fig. 8 diagrammatically illustrates a further embodiment of a control system, including a showing of certain interlocks or protective devices of the system.

Fig. 9 is a diagrammatic view of a three-element control system.

Figs. 1, 2, 3, 4 and 5 substantially duplicate figures of the same numbers in the copending Bailey and Hardgrove application. In view of the reference to this application it is not deemed necessary here to include a lengthy description of the construction and general mode of operation of the referred to type of fluid heater. While in its broader aspects our present invention is adapted for the use of liquid and gaseous fluids as the heated and/or heating fluids, the method and apparatus of our invention are particularly adapted for the use of high temperature gases as the heating fluid and a gaseous fluid, such as a gas, vapor or finely divided solid in suspension, as the fluid to be heated to a high temperature.

The heating unit illustrated in the drawings

is constructed and designed for the use of gaseous heating and heated fluids under pressure, and as shown comprises as its main part an upper heating chamber 10 normally partly filled with a downwardly moving fluent gas-pervious mass of refractory heat transfer material 14 to be heated by high temperature gases while passing therethrough. There is shown a connected subjacent heat absorbing or reaction chamber 11 arranged to receive, and normally substantially completely filled with, heated refractory material 14 from the upper chamber and in which the heated refractory material is utilized for heating a second fluid, in the present embodiment a gaseous fluid, to a predetermined temperature. An elevator 12 is provided receiving the cooled refractory material from the lower chamber 11, returning it to the upper part of the upper chamber 10, and a control system providing automatic control means for regulating operating conditions in the system.

An annular combustion chamber 21 is provided having an annular passage 28 comprising an outlet from the combustion chamber for the heated products of combustion to the fluent mass of material 14. While various fuels can be burned in the combustion chamber 21 to provide the desired supply of high temperature gases, or flue gases from other apparatus introduced as a source of heat, a gaseous fuel is used in the embodiment illustrated. Tangential burners are arranged in diametrically opposite parts of the combustion chamber wall. An air supply connection 34 and a fuel supply 38 provide the elements of combustion to the burners. A valve controlled supply pipe 40 permits additional combustion air or recirculated flue gas to be supplied in variable amounts for tempering the heating gases generated.

The circular cross-section of the upper chamber 10 is progressively decreased to the upper end of a neck or throat passage 42 connecting the chambers 10 and 11. The lower or heat absorbing chamber 11 is of substantially uniform circular horizontal cross-section having near its lower end a valve controlled fluid inlet 52. A gaseous fluid outlet 54 is formed in the upper part of the chamber 11 above the normal level of the fluent mass of material therein. The discharge of refractory material from the chamber 11 is controlled by an adjustable inclined gate 57 at the entrance of a variable speed fluid sealing material discharge device, such as a multi-pocket rotary feeder 59 driven by a variable speed electric motor 60 through a speed reducer 61, as shown in Figs. 1 and 5. The fluent mass of material preferably moved at a relatively uniform rate downwardly through the chamber 10, the throat 42, and the chamber 11, is desirably a high refractory material formed in pellets of approximately one-half inch in diameter.

The feeder 59 empties into the lower inlet of an elevator 12 returning the pellets to the upper inlet pipe 20 of the chamber 10. Speed of the buckets 67 may be controlled by varying the speed of the driving electric motor 68 or through variation of a gear reduction between the two.

In the normal operation of the apparatus described the chambers 10 and 11 and throat 42 are filled with refractory pellets of the desired size and shape to approximately the levels indicated in Fig. 3. The fluent mass of pellets moves continuously downward through the upper chamber, throat, and lower chamber in series, at a relatively slow rate controlled by the position of the gate 57 and the speed of the feeder 59. The desired shape of these chambers and throat causes all portions of the pellet column to move downwardly substantially continuously as long as the feeder is in operation. Fuel is fired in the combustion chamber 21 and the heating gases generated flow through the annular inlet 28 into the lower part of the upper chamber 10, passing upwardly through the interstices in the fluent mass in intimate counter-flow contact with the descending pellets, whereby the pellets are efficiently heated to a high temperature and the gases leave through the heating gas outlet 18 at a relatively low temperature. The highly heated pellets move downwardly in a column through the throat 42 into the lower chamber 11. The gaseous fluid to be heated, such as air, steam, naphtha, etc., is introduced into the chamber 11 through the conduit 52 under a predetermined pressure, passing upwardly through the interstices between the descending pellets in the chamber 11 where it is heated in counterflow heat transfer, and passes out at the desired temperature through the outlet 54. The pellets discharge through the feeder 59, are elevated by the elevator 12, and reenter the chamber 10 through the opening 20.

The relative pressure in the chambers 10 and 11, as well as the flow between the chambers 10 and 11, or lack of flow, is controlled by provisions disclosed in the said Bailey and Hardgrove application.

As diagrammatically illustrated in Fig. 6, the control system may include a differential pressure control responsive to the pressure differential at vertically spaced points in or at opposite sides of the throat 42 for regulating the exit of gaseous fluid from the upper or lower chamber to establish the desired relation between the pressure conditions in the two chambers. Damper regulation of the heating gas outflow from the upper chamber is ordinarily preferred, because of the lower temperature conditions at that point. Differential pressure control apparatus diagrammatically illustrated comprises a transmitter 80 responsive to the pressure differential between the lower part of the upper chamber 10 and the fluid space at the top of the lower chamber 11, and a receiver recorder-controller 82. An air loading pressure is established by the controller 82 representative of the pressure differential and is transmitted to a standardizing relay 83, which established a control pressure then transmitted to a selector valve 84 and thence to a servo-motor 85 arranged to operate a damper 19 in the heating gas outlet 18.

The arrangement is such that upon a departure of the pressure differential from the desired value an immediate and proportional change takes place in the position of the damper 19 in a direction tending to restore the pressure condition in the upper chamber to the desired relative value. Thereafter the standardizing relay operates to gradually position the damper 19 until the pressure in the upper chamber reaches the predetermined desired value. The standardizing relay 83 is of a type described and claimed in Patent 2,098,914 to Harvard H. Gorrie, while the selector valve 84 is described and claimed in Patent 2,202,485 to E. W. Fitch. The selector valve provides a convenient means for transferring operation of the damper 19 from automatic

to manual control if that is desired in starting up or on shutting down the unit.

In Fig. 7 we illustrate the device 80 to larger scale. A particular problem presents itself in measuring or obtaining response to the pressure differential across the throat 42 in that while the fluid in the chamber 10 is usually a substantially dry flue gas the fluid within the chamber 11 may be a condensable vapor or gas, such for example as steam, naphtha, or the like. Thus particular precautions must be taken in the design, construction and installation of the pressure differential responsive device 80 to prevent the possibility of error of measurement caused by false pressure heads produced by condensed vapor in the piping between the point of connection to the chamber 11, and possibly in the device 80 itself. Preferably the device 80 is located at or above the elevation of the pipe 201 connecting it to the chamber 11.

The device 80 is enclosed with a housing 203 capable of withstanding pressures of the order of fifty inches of water, although of course the device may readily be constructed to withstand higher pressures. Within the casing 203, and sealed thereto, is an expansible-contractible metallic bellows 204 dividing the interior of the housing 203 into two chambers 205 and 206. The pipe 200 connects the chamber 10 with the chamber 206, while the pipe 201 connects the chamber 11 with the chamber 205.

Positioned by and with the bellows 204 is an extension arm 207 carrying at its upper end a magnetic core piece 208 positionable relative to coil windings 209, 210 and 211. The core 208 and windings 209, 210, 211 cooperate to form the transmitter of a telemetric system, such as is described and claimed in the copending application of Anthony J. Hornfeck, Serial No. 453,488, now Patent 2,420,539. While we have shown the windings only diagrammatically, it will be appreciated that they would probably be constructed in the form of concentric or end-to-end cylinders surrounding the core piece 208. The pressure differential across the connections 200 and 201 is balanced by a spring 212, which is initially under slight tension and therefore able to move in tension or compression and allow the instrument to work in either direction from a neutral or balanced condition, namely, zero differential pressure relative to the atmosphere. In other words, the instrument is responsive to a plus or minus pressure differential between the chambers 10 and 11, the recording pen of the instrument 82 has its zero part way up on the chart and thus will indicate whether or not the pressure in the throat 42 is balanced, or whether there is a slight flow upwardly or downwardly from one chamber to the other.

In Fig. 6 we illustrate one embodiment of our invention including a constant flow control of the fuel fired to the combustion chamber 21, with the standard of the constant flow control established by temperature of the vapor leaving the chamber 11 through the conduit 54. The principal purpose of the control is to maintain vapor outlet temperature at a predetermined value, returning it to such value upon departure therefrom.

Located in the supply pipe 38 is a regulating valve 213 by which the fuel flow to the furnace 21 may be varied. Normally the rate of application of fuel is automatically maintained constant by means of a constant flow control comprising an orifice 214 disposed in the pipe 38, a differential pressure responsive device 215 responsive to the differential pressure produced by the orifice 214, and a pneumatic pilot valve generally indicated at 216, which is actuated by the responsive device 215 and acts to establish an air loading pressure for positioning the valve 213.

The pilot valve 216 may be of the type illustrated and described in the United States Patent 2,054,464 to Clarence Johnson, and comprises a stationary valve body 217 and a relatively movable valve member 218. The valve body 217 is provided with a centrally located inlet port which may be connected with any suitable source of air under pressure. The air entering the pilot valve passes into a longitudinally located passageway past suitable lands secured to the valve member 218 and is exhausted to the atmosphere. The valve body 217 is also provided with an outlet port 219, the pressure in which will be determined by the position of the lower land on the movable valve member 218. As the valve member 218 moves downwardly the pressure established in the outlet port 219 will proportionately increase and conversely as the movable valve member 218 moves upwardly the pressure established in the outlet port 219 will decrease. The pressure so established in the outlet port is transmitted to a pressure sensitive servo-motor 220 for operating the valve 213. Assuming, by way of example, that the flow of fuel through the pipe 38 increases, the movable valve member 218 will be moved downwardly, thereby increasing the loading pressure in the outlet port 219, and serving to position the valve 213 in a closing direction, thereby tending to return the flow of fuel to the desired rate. A decrease in fuel flow will serve to position the valve member 218 upwardly, thereby decreasing the loading pressure effective on the servo-motor 220, positioning valve 213 in an opening direction and again serving to return the flow of fuel to the desired valve.

The movable valve member 218 is also arranged to be positioned by a cam 221, which serves to establish the desired rate of fuel flow thereafter maintained by the constant flow control. In accordance with our invention the cam 221 is automatically positioned by means responsive to the temperature of the vapor leaving the chamber 11 through the conduit 54 to maintain the temperature of the leaving vapor at a predetermined or desired value. The constant flow control serves the purpose of correcting for changes in the rate of fuel flow, due to variations in fuel pressure, etc. before such changes cause undesirable changes in the temperature of the vapor leaving the chamber 11. In general, it may be said that the temperature responsive apparatus acts to set the control point or standard of the flow control, and thereafter the flow control operates to maintain the actual rate of fuel flow at the control point or standard.

The cam 221 is positioned by a capacitor-run alternating current motor 222 having a wound rotor and stator windings 223 and 224, the latter constituting running coils electrically ninety degrees apart. The motor is provided with a capacitor or condenser 225, which, when the motor is rotating, is in series with either the winding 223 or the winding 224, depending upon the desired direction of rotation. Such a motor runs as a two-phase alternating current motor, and not only may be reversed as to direction of rotation, but is susceptible of speed control when ro-

tating in either direction. While in the present description we have not complicated the drawings by showing the circuit arrangement necessary for such speed control, it will be appreciated that such is possible. The circuit in general is disclosed and claimed in the copending application of Raymond D. Junkins, Serial No. 506,634.

For electrical control of the motor 222 we provide an alternating current Wheatstone bridge generally indicated at 226 and having as arms the resistance 227 and adjustable resistances 228, 229 and 230. The resistance 227 is diagrammatically shown as located in a well or socket in the conduit 54 and has an electrical resistance value varying with temperature of the vapor or fluid leaving the chamber 11 through the conduit 54. Thus the resistance 227 constitutes a variable resistance representative of temperature and forming one arm of the bridge 226. Hand adjustable resistances 228 and 229 provide means for calibrating and adjusting the circuit including the alternating current Wheatstone bridge. The hand adjustable resistance 230 including an indicating scale 231, provides a ready means for establishing the temperature standard (of the vapor outflow) which the system is to maintain.

Variations in electrical resistance of the element 227 (produced by variations in temperature of the vapor outflow) results in an unbalance of the bridge 226 as to polarity or phase of the current in the conjugate conductor 232, with respect to the polarity or phase of the current produced by the source 233. We employ this change in polarity or phase, through an amplifier 237, to selectively operate the motor 222 in one direction or the other to vary the position of the cam 221.

We have shown the mechanical connection between the motor 222 and cam 221 diagrammatically, it being understood that suitable reducing gears, etc. may be employed so that the cam 221 is normally positioned between suitable angular limits of less than 360° over the operating range of the control apparatus. When the temperature of the outflowing vapor (as reflected by the resistance value 227) is at the desired value then the cam 221 will be in predetermined position and the system in equilibrium.

Should the rate of supply of fuel through the conduit 38 vary for any reason, such for example as variations in supply pressure, then the pressure differential responsive device 215 will position the pilot stem 218 to slightly increase or decrease the opening of the control valve 213, thereby correcting the rate of supply of fuel to the flow rate value which is desirably to be maintained constant. This is the operation for any fixed position of the cam 221 representative of a predetermined temperature of the vapor outflow past the resistance 227.

Should the vapor outflow temperature vary in one direction or the other from the desired standard (assuming that the rate of supply of fuel has remained constant) then the consequent variation in resistance 227, and unbalance of the bridge 226 thereby, will result in the motor 222 positioning the cam 221 to slightly raise or lower the pilot stem 218 and control the valve 213 to correct the rate of fuel supply to overcome the deviation of vapor outflow temperature from desired temperature value.

The system described provides a "floating" control or effect characterized by the fact that whenever the actual temperature is other than that desired the rate of application of the corrective agent (fuel) is varied in direction tending to restore the temperature to the desired value. Thus the system will not tend to stabilize out at some vapor outflow temperature other than the desired temperature.

In general the control system provides a constant flow control of the fuel fired to the combustion chamber 21, reset from vapor outflow temperature, to maintain vapor outflow temperature at a predetermined value. The embodiment described in connection with Fig. 6 provides for a very speedy response in heat input to the pellets following any deviation in fuel supply rate or any deviation of vapor outflow temperature from desired temperature through any cause whatsoever.

In Fig. 8 we illustrate another embodiment of our invention, which in general utilizes vapor outflow temperature as a controlling factor for simultaneous control of the rate of supply of fuel to the combustion space 21 and of the rate of circulation of the pellets through a control of the speed of the pellet feeder 59. As we have previously pointed out, the temperature of the vapor leaving the chamber 11 may be varied either by varying the firing and thereby the temperature to which the pellets are heated, or by varying the speed of circulation of the pellets from the chamber 10 to and through the chamber 11 and thereby the rate of heat transfer from the pellets to the vapor passing through the chamber 11. In order that a check may be kept upon the temperature to which the pellets themselves are raised, we provide means sensitive to the temperature of the pellets for resetting the control valve in the fuel gas supply line.

The resistance thermometer, including the temperature sensitive element 227, is similar to that described in connection with Fig. 6 wherein departures of vapor outflow temperature from predetermined optimum temperature effect a rotation of the motor 222 in one direction or the other. The motor 222 mechanically positions one end of a floating link 239 through necessary gear or linkage reduction. The motor 222 also is connected to position the movable element of a motor control rheostat 240 regulating the speed of the motor 60 which drives the feeder 59. It is apparent that the motor 222 might equally as well be connected to vary the actuation of the speed reducer 61 between the motor 60 and the feeder 59. Thus it will be seen that the motor 222, sensitive to temperature of the vapor outflow through the conduit 54, is simultaneously effective in varying the rate of feed of the pellets out of the chamber 11 and upon the control valve 213 for the fuel supply to the combustion chamber 21.

We provide a radiation pyrometer having a temperature sensitive element 241 arranged to look at the pellets in the throat 42. We believe that this is a logical place to obtain pellet temperature, although we might desire to arrange the radiation element 241 to look at the pellets at some point in the chamber 10 above the throat 42 or at some point in the chamber 11 below the throat 42 without limiting the scope of our invention.

For positioning the other end of the floating link 239 we provide a motor 242 having opposed pole windings 243 and 244 controlled by differentially regulating the reactance of a circuit in which they are included. Connected in circuit with the pole winding 243 is a condenser 245 and the output winding 246 of a saturable core reactor 247. Connected in circuit with the pole winding 244 is a condenser 248 and the output

winding 249 of a saturable core reactor 250. The reactor 247 is provided with a control winding 251 and a separately excited adjustable bias winding 252. The reactor 250 is similarly provided with a control winding 253 and a bias winding 254 connected in parallel with the bias winding 252.

The control windings 251 and 253 are connected in series to the device 241 which produces a potential corresponding to the temperature of the pellets. While we have shown the photoelectric device 241 as comprising a photovoltaic cell disposed to look at the pellets within the throat 42 and producing a potential corresponding to the radiation emanating therefrom, it is evident that equivalent means such as a thermocouple or thermo-pile could be employed. The particular arrangement and functioning of the circuit utilizing said potential in control of the motor 242 is described and claimed in Patent 2,310,955 to Hornfeck.

A particular advantage of using the radiation type pyrometer, which we have described, is that it will have a considerably greater life than any thermocouple or resistance thermometer or other temperature sensitive element which might be of necessity inserted directly into the moving column of pellets. The temperature is extremely high and the abrasive action of refractory pellets presents a very serious problem.

In Fig. 8 we have also illustrated schematically a combination of interlocks which we have felt it advisable to provide in the operation of this type of heater in connection with the control which we have invented.

1. Should the feeder 59 stop, with consequent stoppage of circulation of the pellets through the chambers 10 and 11, it is desirable that the heating be discontinued.

2. Should the supply of vapor to the chamber 11 be interrupted, then the heating should be diminished or discontinued and the feeder stopped.

3. Should the pressure of the air supplied for combustion decrease below a predetermined minimum then the heating should be discontinued.

4. Should the elevator stop, and thus the circulation of pellets be interrupted, the heating should be discontinued and the feeder stopped.

5. If the pellet temperature, as measured by the radiation pyrometer, reaches an upper limit, then the heating should be discontinued.

A practical way of discontinuing the heating is, of course, to shut off the supply of fuel through the conduit 38 to the combustion chamber 21. We therefore show positioned in the fuel line 38 a solenoid actuated valve 255 adapted to shut off the supply of fuel to the furnace when the solenoid is deenergized.

In the control circuit of the feeder motor 60 we illustrate a relay 256 adapted to become deenergized and thus open a circuit when the motor 60 is not receiving running current. In the motor circuit of the elevator motor we illustrate a solenoid 257 arranged to be deenergized and thus open a circuit when the elevator motor is not receiving running current. Connected to the air supply pipe 34 we illustrate a Bourdon tube 258 sensitive to pressure of the air and for mechanically actuating a mercury switch 259 to open the circuit of said mercury switch when the air pressure decreases below a certain value. We have indicated in connection with the vapor supply conduit 52 a butterfly type flow indicator 260 adapted to break an electric circuit, through a mercury switch 261, when flow of vapor through the conduit 52 decreases below a predetermined minimum. We illustrate the motor 242, positioned responsive to the radiation pyrometer, being adapted to actuate a mercury switch 262 to open an electric circuit when the temperature of the pellets reaches a predetermined high value.

In Fig. 8 we have shown the system in a non-operating condition with the hand actuated switches 276 and 277 open, the solenoid valve 255 deenergized and closed, and no flow of liquid entering through the conduit 52. The relay 275 is deenergized and open circuited. The relays 256 and 257 are deenergized and open circuited. Pressure of the air for combustion is below a predetermined minimum so that the mercury switch 259 is open circuited. The mercury switches 261 and 262 are both shown in open circuited condition.

In general, the solenoid valve 255 is normally energized from a source of power 263 and held open for free flow of fuel through the conduit 38. Any one of the safety devices 261, 256, 257, 259 or 262 is arranged to open the circuit of the solenoid valve 255 and cause that valve to close off the supply of fuel to the furnace. Thus under any one of the predetermined emergency operating conditions the heating, as represented by the supply of fuel to the furnace, will be discontinued and avoid a dangerous temperature condition within the chambers 10 or 11 or the throat 42.

Under certain conditions it is desirable to stop the pellet feeder 59 and we have therefore included a relay 275 in the control circuit of the motor 60. Under normal operating conditions the circuit closer of the relay 275 is at closed circuit position. In the event of emergency condition then the relay 275 becomes deenergized and the motor control circuit for the motor 60 is opened. In order that the motor 60 may be started by hand we provide a switch 276 by-passing the relay contact 275.

At 277 we provide a hand switch for holding open the solenoid valve 255 in the fuel supply line so that the system may be started by initiating combustion in the chamber 21.

In Fig. 9 we illustrate a three-element type of control arrangement wherein rate of fuel supply is balanced against rate of supply of the fluid entering the chamber 11 to be heated. Such relationship is readjusted or modified, if necessary, in accordance with the temperature of the fluid leaving the chamber 11 after it has been heated.

A differential pressure responsive device 278, similar to the device 215 of Fig. 6, is arranged to position the pilot valve 279 to establish a loading pressure representative of the rate of supply of fuel to the combustion chamber 21. In similar manner a differential pressure responsive device 280 establishes a loading pressure representative of the rate of supply of fluid to the chamber 11 through the conduit 52.

The loading pressures mentioned are transmitted to a ratio relay 281 producing a loading pressure in the pipe 282 representative of the relation between, or ratio of, the two rates of flow.

Such loading pressure is effective within a chamber of the standardizing relay 283. To this relay is also conducted a loading pressure established by the pilot 284 representative of temperature of the fluid leaving the chamber 11 through the conduit 54. The pilot 284 is positioned by a motor 285 under the control of an electrical network including a thermocouple 286.

The thermocouple circuit for control of the motor 285 may be a known potentiometer and amplifying circuit.

From the standardizing relay 283 the loading pressure is effective (through a selector valve 287) in positioning a control valve 288 regulating the rate of supply of fuel to the combustion chamber 21.

In general, the system illustrated in Fig. 9 balances the rate of supply of fuel (for heating the pellets in the chamber 10) against the rate of supply of fluid to be heated entering the chamber 11 through the conduit 52. If the B. t. u. value of the fuel, the temperature of the fluid entering through the conduit 52, and other variables remain constant, then the rate of supply of fuel proportioned to the rate of supply of fluid to be heated could adequately regulate the valve 288.

The tie-back, or third element, in the system is the use of the final result, namely, temperature of the fluid after it has been heated in the chamber 11. By modifying the control of the valve 288 from this fluid outlet temperature we incorporate in the control of the valve 288 any modification which is necessary to satisfy variables in the operation of the system.

While in the arrangement of Figs. 6 and 8 we have illustrated the temperature element 227 as a resistance type it will be appreciated that this might equally as well be the thermocouple type illustrated at 286 of Fig. 9. The choice as between resistance element or thermocouple (with the necessary circuit arrangement in connection therewith) depends to a great extent upon the temperature range expected.

While we have illustrated and described certain preferred embodiments of our invention, it will be understood that these are illustrative only and that the salient features of the invention may be carried out in other manner and with other apparatus than those specifically described.

Certain features of our invention, disclosed but not claimed herein, are disclosed and claimed in our copending divisional application Serial No. 715,044, filed Dec. 9, 1946.

What we claim as new, and desire to secure by Letters Patent of the United States, is:

1. The combination with a fluid heater having an upper chamber enclosing a fluent mass of refractory pellets, a lower chamber enclosing a fluent mass of refractory pellets, a passage forming a throat of reduced cross-section between said upper and lower chambers and enclosing a column of refractory pellets connecting said masses, means external of said chambers and throat arranged to return pellets from an exit in the lower chamber to an inlet to the upper chamber, a fuel supply means for heating the pellets in the upper chamber, a supply of fluid to be heated passing through the lower chamber in direct contact with the heated pellets therein, and means regulating the fuel supply rate responsive to both heated fluid temperature and temperature of the heated pellets.

2. The combination with a fluid heater having an upper chamber enclosing a fluent mass of solid material, a lower chamber enclosing a fluent mass of solid material, a passage forming a throat of reduced cross-section between said upper and lower chambers and enclosing a column of fluent solid material connecting said masses, means external of said chambers and throat arranged to return said material from an exit in the lower chamber to an inlet to the upper chamber, a fuel supply means for heating the solid material in the upper chamber, a supply of fluid to be heated passed through the lower chamber in direct contact with the heated material therein, and means regulating the fuel supply rate responsive to temperature of the solid material leaving the upper chamber.

3. The combination with a fluid heater having an upper chamber enclosing a fluent mass of refractory pellets, a lower chamber enclosing a fluent mass of refractory pellets, a passage forming a throat of reduced cross-section between said upper and lower chambers and enclosing a column of refractory pellets connecting said masses, means external of said chambers and throat arranged to return pellets from an exit in the lower chamber to an inlet to the upper chamber, a fuel supply means for heating the pellets in the upper chamber, a supply of fluid to be heated passed through the lower chamber in direct contact with the heated pellets therein, means regulating the fuel supply rate responsive to both heated fluid temperature and temperature of the heated pellets, and means regulating the rate of movement of the pellets from the upper to the lower chamber responsive to temperature of the heated fluid leaving the lower chamber.

4. The combination with a fluid heater having an upper chamber enclosing a fluent mass of refractory pellets, a lower chamber enclosing a fluent mass of refractory pellets, a passage forming a throat of reduced cross-section between said upper and lower chambers and enclosing a column of refractory pellets connecting said masses, means external of said chambers and throat arranged to return pellets from an exit in the lower chamber to an inlet to the upper chamber, a feeder at the exit of the lower chamber feeding pellets at a regulable rate from the lower chamber to the returning means, a heating supply for the pellets in the upper chamber, a supply of fluid to be heated passing through the lower chamber in direct contact with the heated pellets therein, and means sensitive to the temperature of the fluid leaving the lower chamber adapted to regulate the feeder speed.

5. The combination of claim 4 including means sensitive to a discontinuance of feeder operation adapted to discontinue the heating supply.

6. The method of operating apparatus having an upper chamber enclosing a fluent mass of solid material, a lower chamber enclosing a fluent mass of solid material, and a throat of reduced cross-section connecting the upper and lower chambers and enclosing a fluent mass of the solid material connecting the upper and lower chamber masses; which includes maintaining a substantially continuous flow of solid material downwardly through the upper chamber, throat and lower chamber, continuously supplying a heating medium to the upper chamber in direct contact with the solid material therein, continuously supplying a fluid to be heated to the lower chamber in direct contact with the mass of solid material therein, and controlling the rate of supply of the heating medium responsive to temperature of the heated solid material.

7. The method of operating apparatus having an upper chamber enclosing a fluent mass of solid material, a lower chamber enclosing a fluent mass of solid material, and a throat of reduced cross-section connecting the upper and lower chambers and enclosing a fluent mass of the solid material connecting the upper and lower chamber masses; which includes maintaining a substantially continuous flow of solid material

downwardly through the upper chamber, throat and lower chamber, continuously supplying a heating medium to the upper chamber in direct contact with the solid material therein, continuously supplying a fluid to be heated to the lower chamber in direct contact with the solid material therein, and controlling the rate of supply of the heating medium jointly responsive to temperature of the fluid after it has been heated by contact with the material in the lower chamber and to temperature of the heated material.

8. The method of operating apparatus having an upper chamber enclosing a fluent mass of solid material, a lower chamber enclosing a fluent mass of solid material, and a throat of reduced cross-section connecting the upper and lower chambers and enclosing a fluent mass of the solid material connecting the upper and lower chamber masses; which includes maintaining a substantially continuous flow of solid material downwardly through the upper chamber, throat and lower chamber, continuously supplying a heating medium to the upper chamber in direct contact with the solid material therein, continuously supplying a fluid to be heated to the lower chamber in direct contact with the solid material therein, and utilizing the temperature of the fluid after it has been heated to conjointly control the rate of supply of heating medium and the rate of downward flow of the solid material.

9. The method of operating apparatus having an upper chamber enclosing a fluent mass of solid material, a lower chamber enclosing a fluent mass of solid material, and a throat of reduced cross-section connecting the upper and lower chambers and enclosing a fluent mass of the solid material connecting the upper and lower chamber masses; which includes maintaining a substantially continuous flow of solid material downwardly through the upper chamber, throat and lower chamber, continuously supplying a heating medium to the upper chamber in direct contact with the solid material therein, continuously supplying a fluid to be heated to the lower chamber in direct contact with the solid material therein, utilizing the temperature of the fluid after it has been heated to conjointly control the rate of supply of heating medium and the rate of downward movement of the solid material, and modifying the control of the supply of heating medium responsive to temperature of the heated solid material.

10. The method of operating a fluid heater of the type having two chambers connected by a throat with heat transfer material in each of the chambers and in the throat and having provision for substantially continually moving such material from the first chamber through the throat to the second chamber and exteriorly from the second chamber back to the first chamber including, maintaining a supply of heating medium to the first chamber to heat the material as it passes therethrough, passing a fluid to be heated through the second chamber in direct contact with the heated material passing therethrough, regulating the rate of supply of the heating medium responsive to temperature of the heated fluid, and automatically stopping the supply of heating medium under any one of several predetermined emergency conditions.

11. A method of operating a fluid heater of the type having two chambers connected by a throat with heat transfer material in each of the chambers and in the throat and having provision for substantially continually moving such material from the first chamber through the throat to the second chamber and exteriorly from the second chamber back to the first chamber including, maintaining a supply of heating medium to the first chamber to heat the material as it passes therethrough, passing a fluid to be heated through the second chamber in direct contact with the heated material passing therethrough, regulating the rate of supply of the heating medium responsive to temperature of the heated fluid, and automatically stopping the heating upon occurrence of an interruption to material movement through the system.

12. The method of operating a fluid heater of the type having two chambers connected by a throat with heat transfer material in each of the chambers and in the throat and having provision for substantially continually moving such material from the first chamber through the throat to the second chamber and exteriorly from the second chamber back to the first chamber, including, maintaining a supply of heating medium to the first chamber to heat the material as it passes therethrough, passing a fluid to be heated through the second chamber in direct contact with the heated material passing therethrough, regulating the rate of supply of the heating medium responsive to temperature of the heated fluid, and automatically stopping the supply of heating medium when the rate of supply of the fluid decreases to a predetermined minimum.

13. The method of operating a fluid heater of the type having two chambers connected by a throat with heat transfer material in each of the chambers and in the throat and having provision for substantially continually moving such material from the first chamber through the throat to the second chamber and exteriorly from the second chamber back to the first chamber, including, maintaining a supply of heating medium to the first chamber to heat the material as it passes therethrough, passing a fluid to be heated through the second chamber in direct contact with the heated material passing therethrough, regulating the rate of supply of the heating medium responsive to temperature of the heated fluid, and automatically discontinuing both the supply of heating medium and the movement of the heat transfer material through the system when the rate of supply of the fluid decreases to a predetermined minimum.

14. The method of operating a fluid heater of the type having two chambers connected by a throat with heat transfer material in each of the chambers and in the throat and having provision for substantially continually moving said material from the first chamber through the throat to the second chamber and exteriorly from the second chamber back to the first chamber, including, maintaining a supply of heating medium to the first chamber to heat the material as it passes therethrough, passing a fluid to be heated through the second chamber in direct contact with the heated material passing therethrough, regulating the rate of supply of the heating medium responsive to temperature of the heated fluid, and automatically discontinuing the heating when a variable condition of the heating medium decreases below a minimum value.

15. The method of operating a fluid heater of the type having two chambers connected by a throat with heat transfer material in each of the chambers and in the throat and having provision for substantially continually moving such material from the first chamber through the throat to the second chamber and exteriorly from

the second chamber back to the first chamber, including, maintaining a supply of heating medium to the first chamber to heat the material as it passes therethrough, passing a fluid to be heated through the second chamber in direct contact with the heated material passing therethrough, regulating the rate of supply of the heating medium responsive to temperature of the heated fluid, and automatically discontinuing the heating upon occurrence of an interruption to material movement exteriorly from the second chamber back to the first chamber.

16. The method of operating a fluid heater of the type having two chambers connected by a throat with heat transfer material in each of the chambers and in the throat and having provision for substantially continually moving such material from the first chamber through the throat to the second chamber and exteriorly from the second chamber back to the first chamber, including, maintaining a supply of heating medium to the first chamber to heat the material as it passes therethrough, passing a fluid to be heated through the second chamber in direct contact with the heated material passing therethrough, regulating the rate of supply of the heating medium responsive to temperature of the heated fluid, and automatically discontinuing both the heating and the movement of heat transfer material through the heater upon occurrence of an interruption to movement of the heat transfer material exteriorly from the second chamber back to the first chamber.

17. The method of operating a fluid heater of the type having two chambers connected by a throat with heat transfer material in each of the chambers and in the throat and having provision for substantially continually moving such material from the first chamber through the throat to the second chamber and exteriorly from the second chamber back to the first chamber, including, maintaining a supply of heating medium to the first chamber to heat the material as it passes therethrough, passing a fluid to be heated through the second chamber in direct contact with the heated material passing therethrough, regulating the rate of supply of the heating medium responsive to temperature of the heated fluid, and automatically discontinuing the heating when the temperature of the heat transfer material leaving the first chamber exceeds a predetermined value.

18. The combination with a fluid heater having an upper chamber enclosing a fluent mass of solid heat transfer material, a lower chamber enclosing a fluent mass of solid heat transfer material, a passage forming a throat between said upper and lower chambers and enclosing a fluent mass of solid heat transfer material connecting said material masses, means external of said chambers and throat to return the material from an exit in the lower chamber to an inlet to the upper chamber, a feeder at the exit of the lower chamber feeding material at a regulable rate from the lower chamber to the returning means, a heating supply for the material in the upper chamber, a supply of fluid to be heated passed through the lower chamber in direct contact with the heated material therein, means sensitive to the temperature of the fluid leaving the lower chamber adapted to regulate the rate of heating supply, and means arranged to shut off the supply of heating responsive to failure of the feeder.

19. The combination with a fluid heater having an upper chamber enclosing a fluent mass of solid heat transfer material, a lower chamber enclosing a fluent mass of solid heat transfer material, a passage forming a throat between said upper and lower chambers and enclosing a fluent mass of solid heat transfer material connecting said material masses, means external of said chambers and throat to return the material from an exit in the lower chamber to an inlet to the upper chamber, a feeder at the exit of the lower chamber feeding material at a regulable rate from the lower chamber to the returning means, a heating supply for the material in the upper chamber, a supply of fluid to be heated passed through the lower chamber in direct contact with the heated material therein, means sensitive to the temperature of the fluid leaving the lower chamber adapted to regulate the rate of heating supply, and means responsive to the rate of supply of the fluid adapted to discontinue the heating supply when the rate of supply of the fluid to be heated decreases to a predetermined minimum.

20. The combination with a fluid heater having an upper chamber enclosing a fluent mass of solid heat transfer material, a lower chamber enclosing a fluent mass of solid heat transfer material, a passage forming a throat between said upper and lower chambers and enclosing a fluent mass of solid heat transfer material connecting said material masses, means external of said chambers and throat to return the material from an exit in the lower chamber to an inlet to the upper chamber, a feeder at the exit of the lower chamber feeding material at a regulable rate from the lower chamber to the returning means, a heating supply for the material in the upper chamber, a supply of fluid to be heated passed through the lower chamber in direct contact with the heated material therein, means sensitive to the temperature of the fluid leaving the lower chamber adapted to regulate the rate of heating supply, and means responsive to the rate of supply of the fluid adapted to discontinue the supply of heating medium and to stop the feeder when the rate of supply of the fluid to be heated decreases to a predetermined minimum value.

21. The combination with a fluid heater having an upper chamber enclosing a fluent mass of solid heat transfer material, a lower chamber enclosing a fluent mass of solid heat transfer material, a passage forming a thrbat between said upper and lower chambers and enclosing a fluent mass of solid heat transfer material connecting said material masses, means external of said chambers and throat to return the material from an exit in the lower chamber to an inlet to the upper chamber, a feeder at the exit of the lower chamber feeding material at a regulable rate from the lower chamber to the returning means, a heating supply for the material in the upper chamber, a supply of fluid to be heated passed through the lower chamber in direct contact with the heated material therein, means sensitive to temperature of the fluid leaving the lower chamber adapted to regulate the rate of heating supply, and means sensitive to the value of a variable condition of the heating adapted to discontinue the heating supply when the value of said variable decreases below a predetermined minimum.

22. The combination with a fluid heater having an upper chamber enclosing a fluent mass of solid heat transfer material, a lower chamber enclosing a fluent mass of solid heat transfer material, a passage forming a throat between said upper and lower chambers and enclosing a fluent

mass of solid heat transfer material connecting said material masses, means external of said chambers and throat to return the material from an exit in the lower chamber to an inlet to the upper chamber, a feeder at the exit of the lower chamber feeding material at a regulable rate from the lower chamber to the returning means, a heating supply for the material in the upper chamber, a supply of fluid to be heated passed through the lower chamber in direct contact with the heated material therein, means sensitive to the temperature of the fluid leaving the lower chamber adapted to regulate the rate of heating supply, and means sensitive to an operating condition of the returning means adapted to discontinue the heating upon failure of the returning means to return material exteriorly from the exit of the second chamber to the entrance of the first chamber.

23. The combination with a fluid heater having an upper chamber enclosing a fluent mass of solid heat transfer material, a lower chamber enclosing a fluent mass of solid heat transfer material, a passage forming a throat between said upper and lower chambers and enclosing a fluent mass of solid heat transfer material connecting said material masses, means external of said chambers and throat to return the material from an exit in the lower chamber to an inlet to the upper chamber, a feeder at the exit of the lower chamber feeding material at a regulable rate from the lower chamber to the returning means, a heating supply for the material in the upper chamber, a supply of fluid to be heated passed through the lower chamber in direct contact with the heated material therein, means sensitive to the temperature of the fluid leaving the lower chamber adapted to regulate the rate of heating supply, and means sensitive to a function of operation of the returning means adapted to discontinue the heating supply and to stop the feeder when the returning means ceases to function.

24. The combination with a fluid heater having an upper chamber enclosing a fluent mass of solid heat transfer material, a lower chamber enclosing a fluent mass of solid heat transfer material, a passage forming a throat between said upper and lower chambers and enclosing a fluent mass of solid heat transfer material connecting said material masses, means external of said chambers and throat to return the material from an exit in the lower chamber to an inlet to the upper chamber, a feeder at the exit of the lower chamber feeding material at a regulable rate from the lower chamber to the returning means, a heating supply for the material in the upper chamber, a supply of fluid to be heated passed through the lower chamber in direct contact with the heated material therein, means sensitive to the temperature of the fluid leaving the lower chamber adapted to regulate the rate of heating supply, and means sensitive to temperature of the heat transfer material adapted to discontinue the heating supply when the temperature of the heat transfer material exceeds a predetermined value.

25. The combination with a fluid heater having an upper chamber enclosing a fluent mass of solid heat transfer material, a lower chamber enclosing a fluent mass of solid heat transfer material, a passage forming a throat between said upper and lower chambers and enclosing a fluent mass of solid heat transfer material connecting said material masses, means external of said chambers and throat to return the material from an exit in the lower chamber to an inlet to the upper chamber, a feeder at the exit of the lower chamber feeding material at a regulable rate from the lower chamber to the returning means and thereby determining the downward movement of heat exchange material through the upper chamber and throat and lower chamber, a heating supply for the material in the upper chamber, a supply of fluid to be heated passed through the lower chamber in direct contact with the heated material therein, and means sensitive to the temperature of the fluid after it has been heated adapted to conjointly control the heating supply means and the feeder.

26. The combination with a fluid heater having an upper chamber enclosing a fluent mass of solid heat transfer material, a lower chamber enclosing a fluent mass of solid heat transfer material, an unobstructed passage forming a throat between said upper and lower chambers and enclosing a fluent mass of solid heat transfer material connecting said material masses, means external of said chambers and throat to return the material from an exit in the lower chamber to an inlet to the upper chamber, a feeder at the exit of the lower chamber feeding material at a regulable rate from the lower chamber to the returning means, a heating supply for the material in the upper chamber, a supply of fluid to be heated passed through the lower chamber in direct contact with the heated material therein, said heating supply comprising the products of combustion of fuel and air, a supply of fuel for combustion, a supply of air for combustion, and means sensitive to the temperature of the fluid leaving the lower chamber adapted to conjointly control the rate of supply of fuel for combustion and said feeder.

27. The combination with a fluid heater having an upper chamber enclosing a fluent mass of solid heat transfer material, a lower chamber enclosing a fluent mass of solid heat transfer material, an unobstructed passage forming a throat between said upper and lower chambers and enclosing a fluent mass of solid heat transfer material connecting said material masses, means external of said chambers and throat to return the material from an exit in the lower chamber to an inlet to the upper chamber, a feeder at the exit of the lower chamber feeding material at a regulable rate from the lower chamber to the returning means, a heating supply for the material in the upper chamber, a supply of fluid to be heated passed through the lower chamber in direct contact with the heated material therein, said heating supply comprising the products of combustion, supply means for the elements of combustion, and means sensitive to the temperature of the fluid leaving the lower chamber adapted to regulate the rate of supply of at least one of the elements of combustion and simultaneously to control the feeder.

28. The method of operating a fluid heater of the type having two chambers connected by a throat with heat transfer material in each of the chambers and in the throat and having provision for substantially continually moving such material from the first chamber through the throat to the second chamber and exteriorly from the second chamber back to the first chamber including, maintaining a supply of heating medium to the first chamber to heat material as it passes therethrough, passing a fluid to be heated through the second chamber in direct contact

with the heated material passing therethrough, regulating the rate of supply of the heating medium responsive to both heated fluid temperature and the temperature of the heat transfer material leaving the first chamber, and regulating the rate of movement of the heat transfer material from the first to the second chamber responsive to a measure of the temperature of the heated fluid leaving the lower chamber.

29. The method of operating a fluid heater of the type having two chambers connected by a throat with heat transfer material in each of the chambers and in the throat and having provision for substantially continually moving such material from the first chamber through the throat to the second chamber and exteriorly from the second chamber back to the first chamber, including, maintaining a supply of heating medium to the first chamber to heat material as it passes therethrough, passing a fluid to be heated through the second chamber in direct contact with the heated material passing therethrough, and regulating the speed of movement of the heat transfer material through the system responsive to the temperature of the fluid after it has been heated.

30. The combination with a fluid heater having an upper chamber enclosing a fluent mass of refractory pellets, a lower chamber enclosing a fluent mass of refractory pellets, a passage forming a throat of reduced cross-section between said upper and lower chambers and enclosing a column of refractory pellets connecting said masses, means external of said chambers and throat arranged to return pellets from an exit in the lower chamber to an inlet to the upper chamber, a feeder at the exit of the lower chamber feeding pellets at a regulable rate from the lower chamber to the returning means, a heating supply for the pellets in the upper chamber, a supply of fluid to be heated passing through the lower chamber in direct contact with the heated pellets therein, and means sensitive to the temperature of the fluid at a predetermined location in its flow path adapted to regulate the feeder speed.

31. The combination of claim 30 including means regulating the fuel supply rate responsive to temperature of the heated pellets.

32. The combination with a fluid heater having an upper chamber enclosing a fluent mass of refractory pellets, a lower chamber enclosing a fluent mass of refractory pellets, a passage forming a throat of reduced cross-section between said upper and lower chambers and enclosing a column of refractory pellets connecting said masses, means external of said chambers and throat arranged to return pellets from an exit in the lower chamber to an inlet to the upper chamber, a regulable means for varying the rate of return of pellets from the lower to the upper chamber, a heating supply for the pellets in the upper chamber, a supply of fluid to be heated passing through the lower chamber in direct contact with the heated pellets therein, and means sensitive to the temperature of the fluid at a predetermined location in it flow path and adapted to control the regulable means.

33. The method of operating a fluid heater of the type having two chambers connected by a throat with heat transfer material in each of the chambers and in the throat and having provision for substantially continually moving such material from the first chamber through the throat to the second chamber and exteriorally from the second chamber back to the first chamber, including maintaining a supply of heating medium to the first chamber to heat material as it passes therethrough, passing a fluid to be heated through the second chamber in direct contact with the heated material passing therethrough, and regulating the speed of movement of the heat transfer material through the system responsive to the temperature of the fluid at a predetermined location.

34. A continuous process for effecting thermal treatment of gases at elevated temperatures which comprises continuously flowing by gravity a fluent mass if hot refractory pellets through a series of substantially vertically extending zones comprising a pellet heating zone and a gas heating zone; continuously contacting that portion of said mass of pellets in said pellet heating zone with a stream of hot combustion gas, thereby substantially heating said pellets; continuously contacting that portion of said mass of pellets in said gas heating zone with a countercurrent stream of gas to be heated, thereby heating said gas a substantial amount; and continuously transferring pellets from the lower portion of said gas heating zone to the upper portion of said pellet heating zone at a rate regulated in response to variations in temperature of the gas being heated.

35. A continuous process for effecting thermal treatment of gases at elevated temperatures which comprises continuously flowing by gravity a fluent mass of hot refractory pellets through a series of subsantially vertically extending zones comprising a pellet heating zone and a gas heating zone; continuously contacting that portion of said mass of pellets in said pellet heating zone with a stream of hot combustion gas, thereby substantially heating said pellets; continuously contacting that portion of said mass of pellets in said gas heating zone with a countercurrent stream of the gas to be heated, thereby heating said gas a substantial amount; continuously transferring pellets from the lower portion of said gas heating zone to the upper portion of said pellet heating zone; and varying the operation in response to variations in pellet temperature.

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No references cited.